Efficient Message Authentication for Spread Spectrum Wireless Communications

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Problem Studied

- *Message authentication* is used to confirm the integrity of a message and the authenticity of its sender.
- Conventionally, message authentication is an *application layer* problem.
- For the class of communications systems considered here, we present message authentication solutions that work at the *physical layer*.

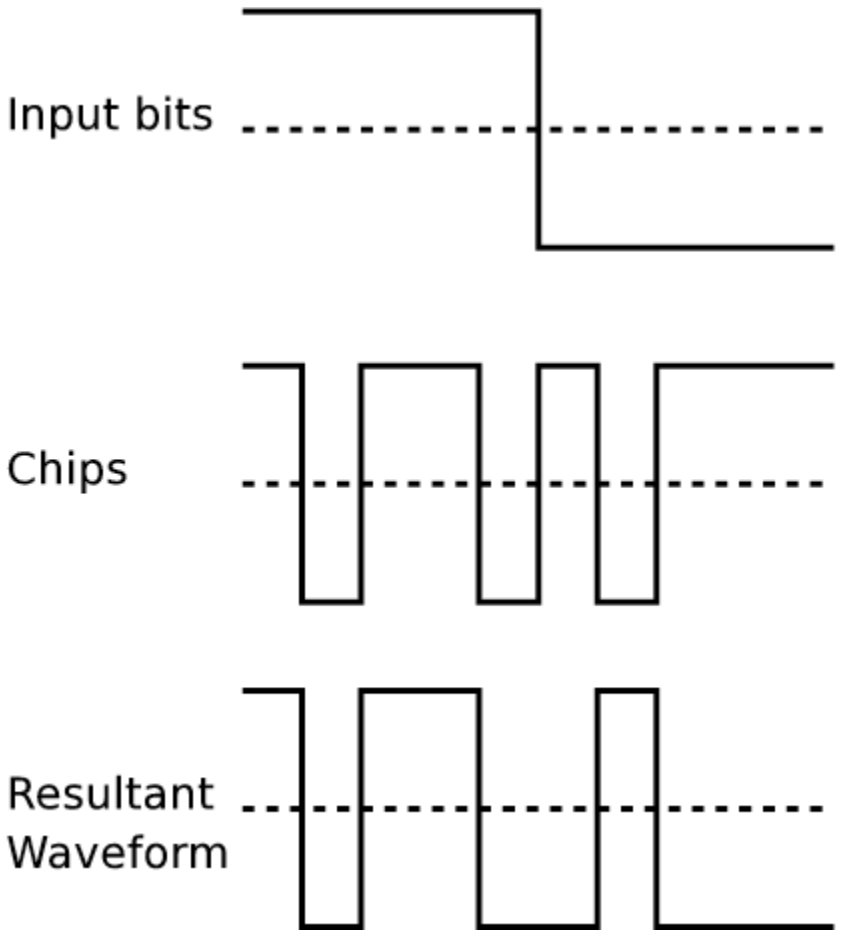
Why?

- Primary reason to consider the physical layer is to reduce communications costs:
  - Saves power
  - Fewer bits or chips needed
  - Better control over *false acceptance* versus *false rejection* tradeoff

Spread Spectrum Communication

- Widely used, especially in military communications
- Each bit is represented by multiple chips
- Sender and receiver use same chip sequence to construct bits
- Spreading gain is the number of chips per bit.

Example: Spread Spectrum



Conventional MAC's

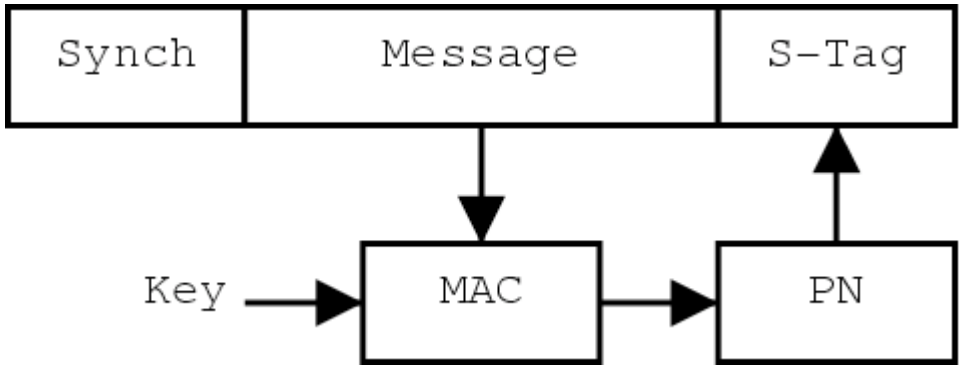
- A *Message Authentication Code* (MAC) is a sequence of bits that depends on message and secret key
- Since only sender and receiver know key, only sender and receiver can create correct MAC
- In wired networks, MAC's are 128 or more bits long
- In wireless networks, MAC's can be much shorter

Minitag Idea

- Our idea, which we call a *minitag*, is to use a sequence of chips, not bits, to represent the MAC.
- The MAC will consist of many chips, but not all have to be received correctly
- (Good thing, since *chip error rate* is much higher than *bit error rate*.)

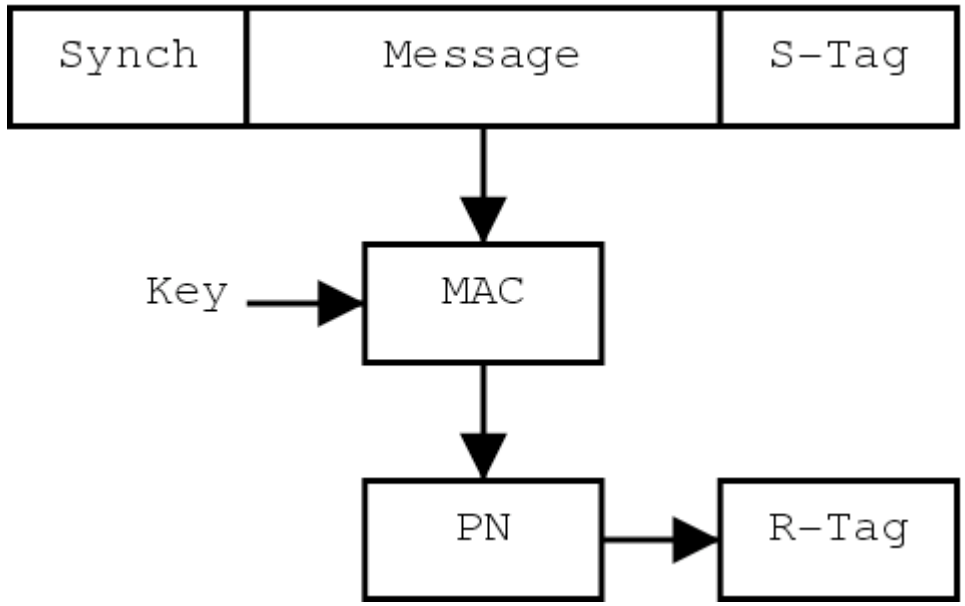
Message Authentication at Sender

- Sender computes tag using secret key



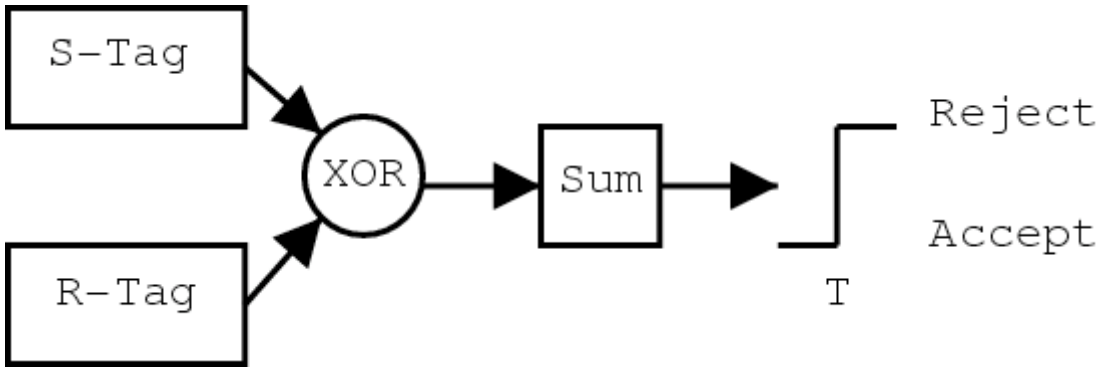
Authentication at Receiver

- Receiver computes tag:



Compare Tags to Verify

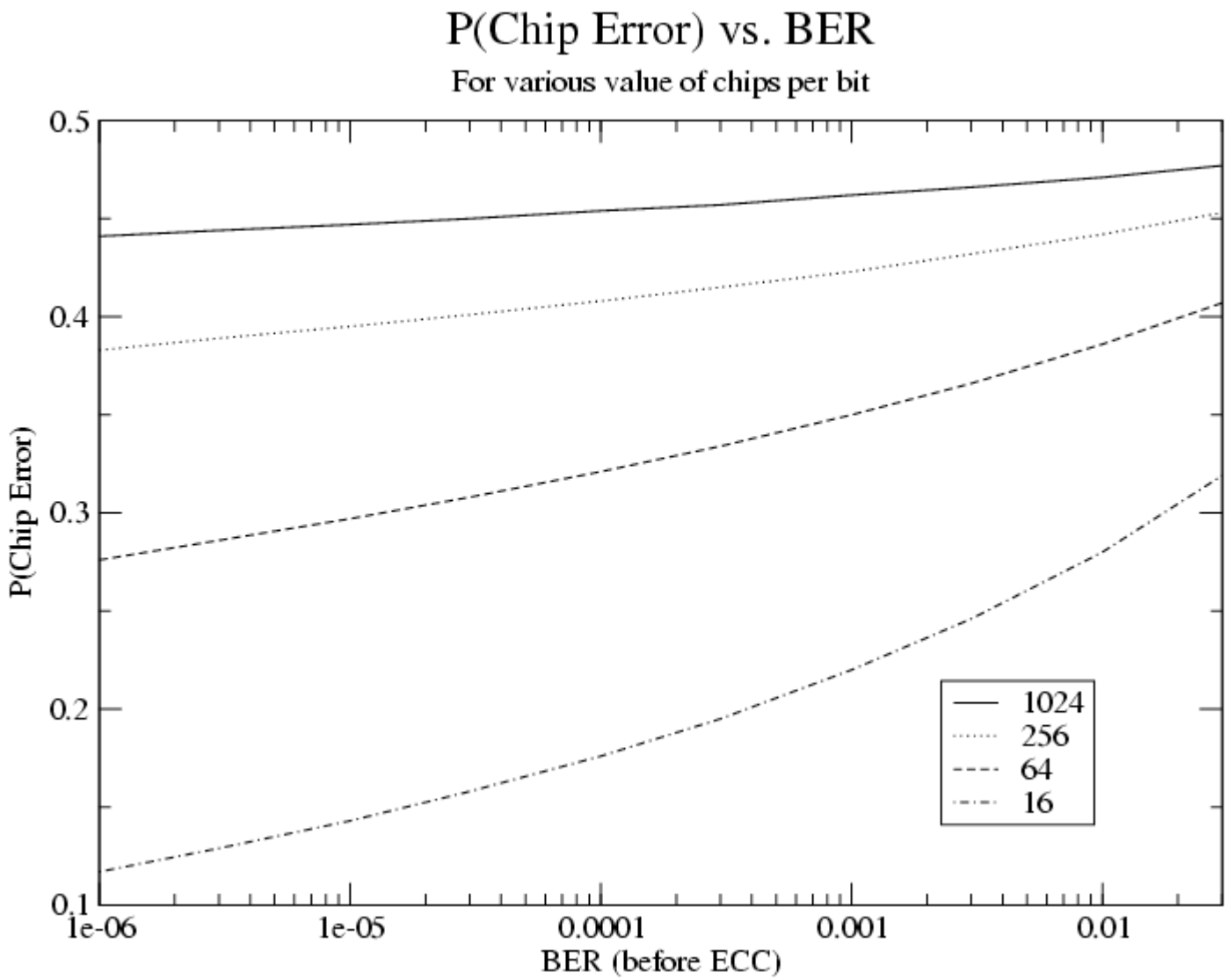
- Receiver compares tags to verify message authentication:



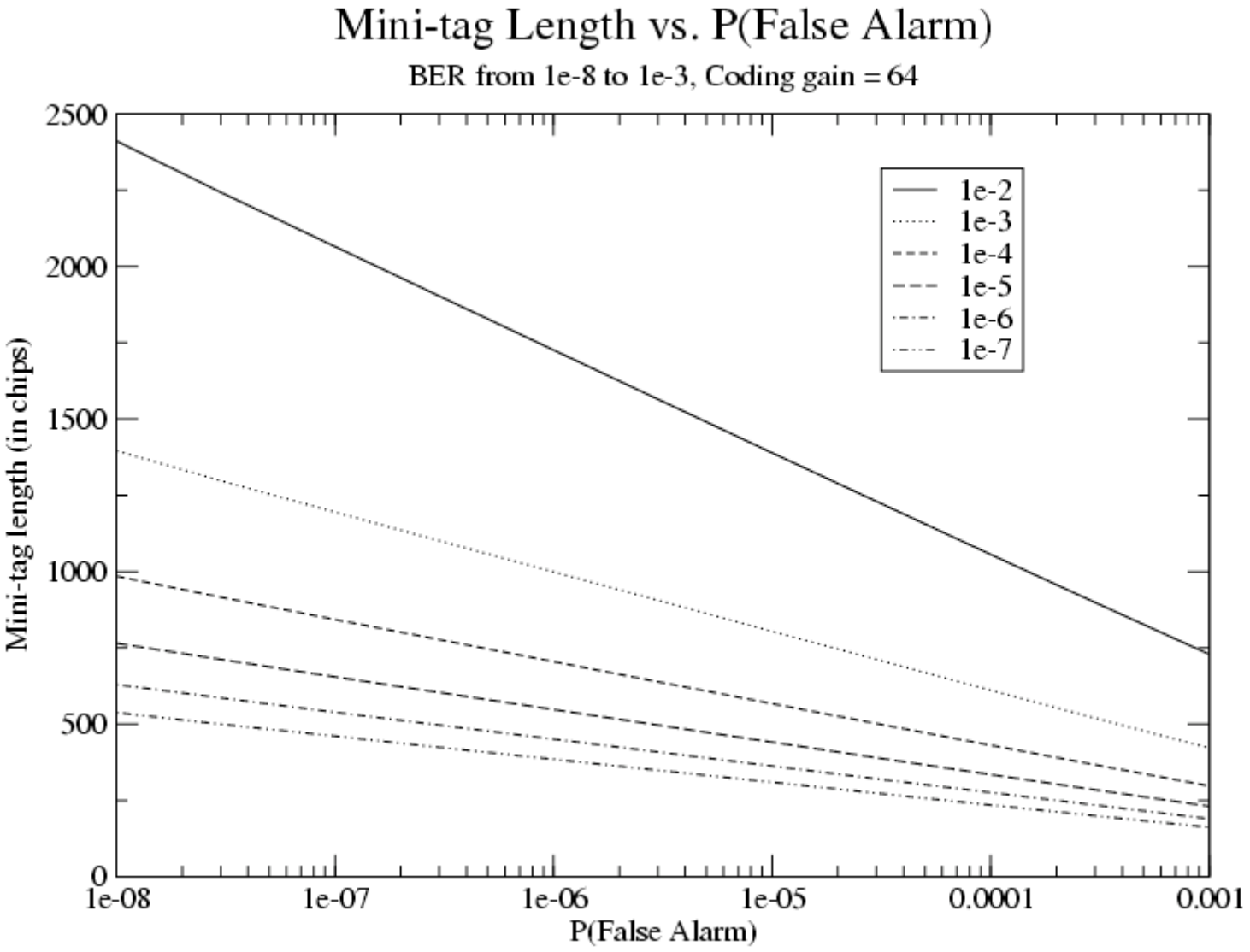
Minitag Analysis

- If message is correct, then all chips agree (except for noise)
- If message is false, then chips disagree with probability 0.5
- Assume Gaussian noise with variance depending on SNR
- Hypothesis becomes: choose between $(0.5)^n$ and $p^l(1-p)^m$ where l = # errors, m = # correct, p = chip error probability

Chip Error Rate



Mintag Length vs. P(False Accept)



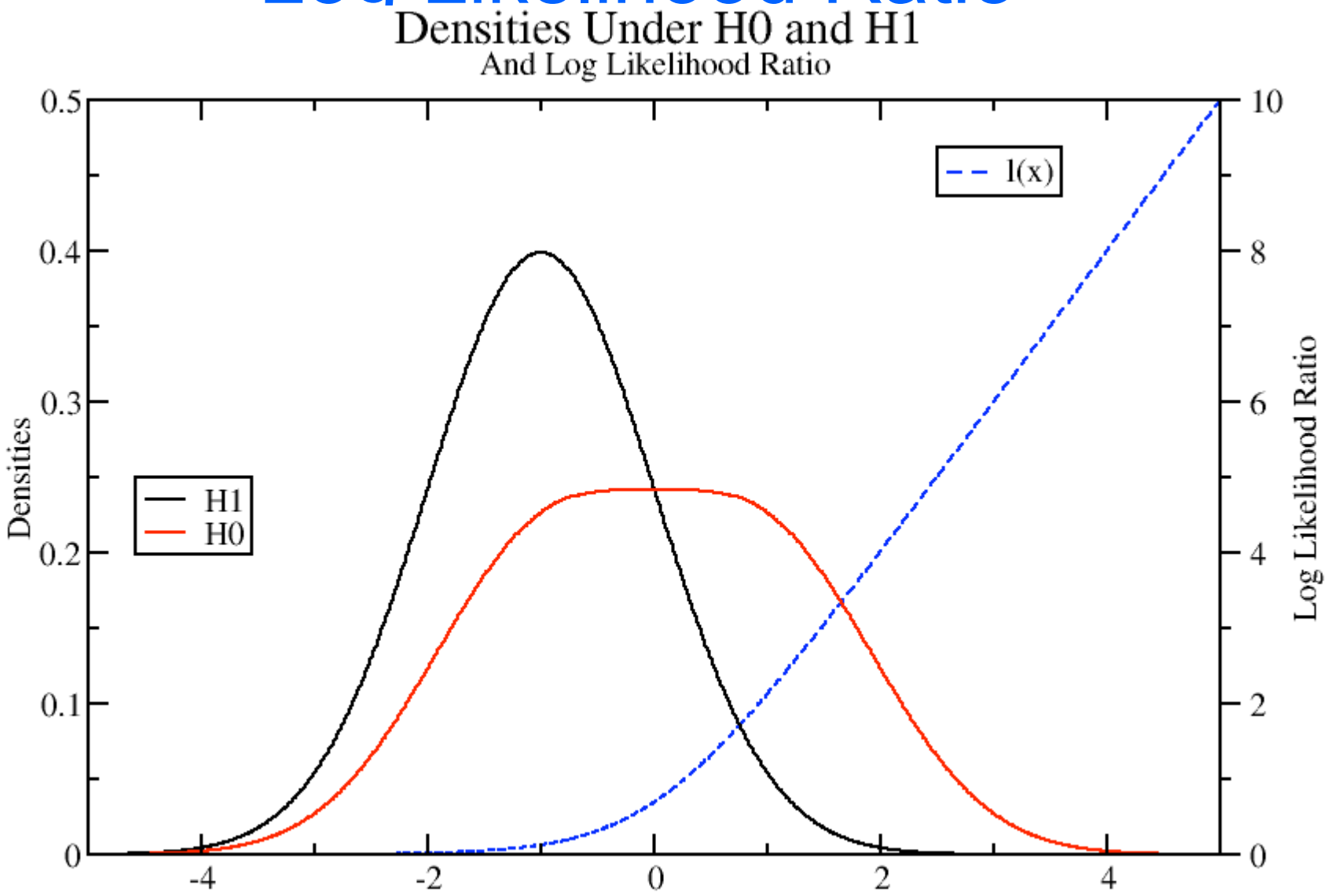
Example: IS-95 CDMA

- Assume BER = 0.001 (before ECC), coding gain = 64, rate 1/2 ECC
- For 1e-7 security, a conventional tag needs 24 bits
- Chips needed = 24 * 2 * 64 = 3072
- Minitag needs 1195 chips, a savings of almost two-thirds

Soft Decision Minitag

- Can use soft decision decoding
- Treat each chip as a Gaussian RV
- If message is correct, all means = -1
- If message is false, means randomly alternate between -1 and 1
- Use central limit theorem for analysis

Log Likelihood Ratio



Soft Decision Performance

- Continuing IS-95 example, chips needed reduced to about 774, a savings of almost a factor of 4 from the original.

Conclusions

- By considering authentication at physical layer, reduced communications cost for message authentication by about 2/3 to 3/4
- Furthermore, we can tune false acceptance and false rejection probabilities
- Future work improving and extending to other communication scenarios.

Thanks

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- The views and conclusions contained in this document are those of the authors and should no be interpreted as representing the official policies, either expressed or implied, of the Army Research Laboratory or the U. S. Government

DSSS Work

- At last year's review, presented work using a “minitag” for authentication.
- The minitag used chips, not bits, by altering the spreading sequence.
- Eg. Assuming coding gain of 64, BER=1e-3, false alarm and miss probabilities = 1e-7, rate=1/2 ECC,
  - Conventional needs 3072 chips
  - Minitag needs 1195 chips

Current Work on Minitag

- Extending to soft decision.
- Ex., can reduce chip length to 772 chips, a factor of 4 reduction from original 3072 chips.
- (Problem is that our analysis uses the central limit theorem, which may be inaccurate at the very small probabilities needed here.)

New Work

- Message authentication is a one bit process:

  Essentially, one decides whether or not the message is authentic.

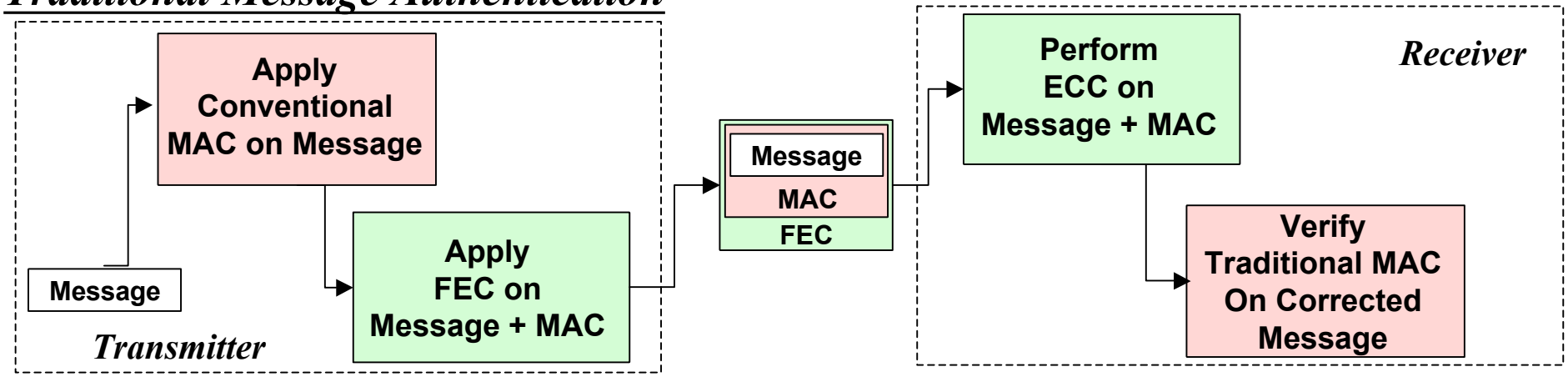
- Also, want to extend to other modulation schemes, not just DSSS.

Idea: Treat bits as a group

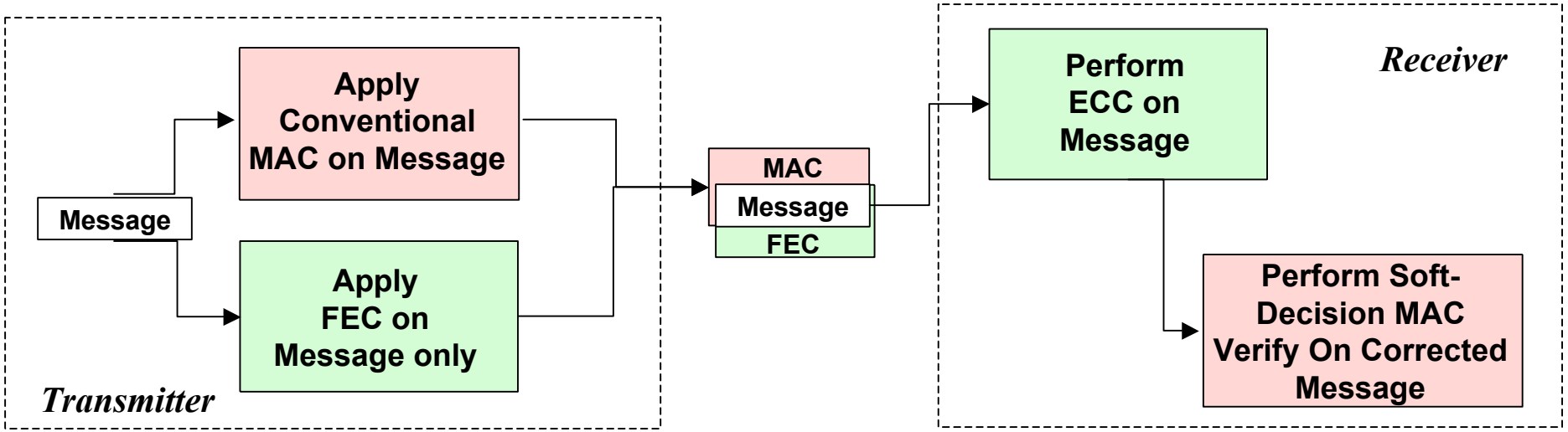
- Send *n* bits as a group. Make a single decision on the group.
- Can do hard or soft decision of each bit in the group.
- Advantages: simplicity, better performance than other methods, applies to many modulation methods.

Traditional vs. Soft-Decision Message Authentication

Traditional Message Authentication



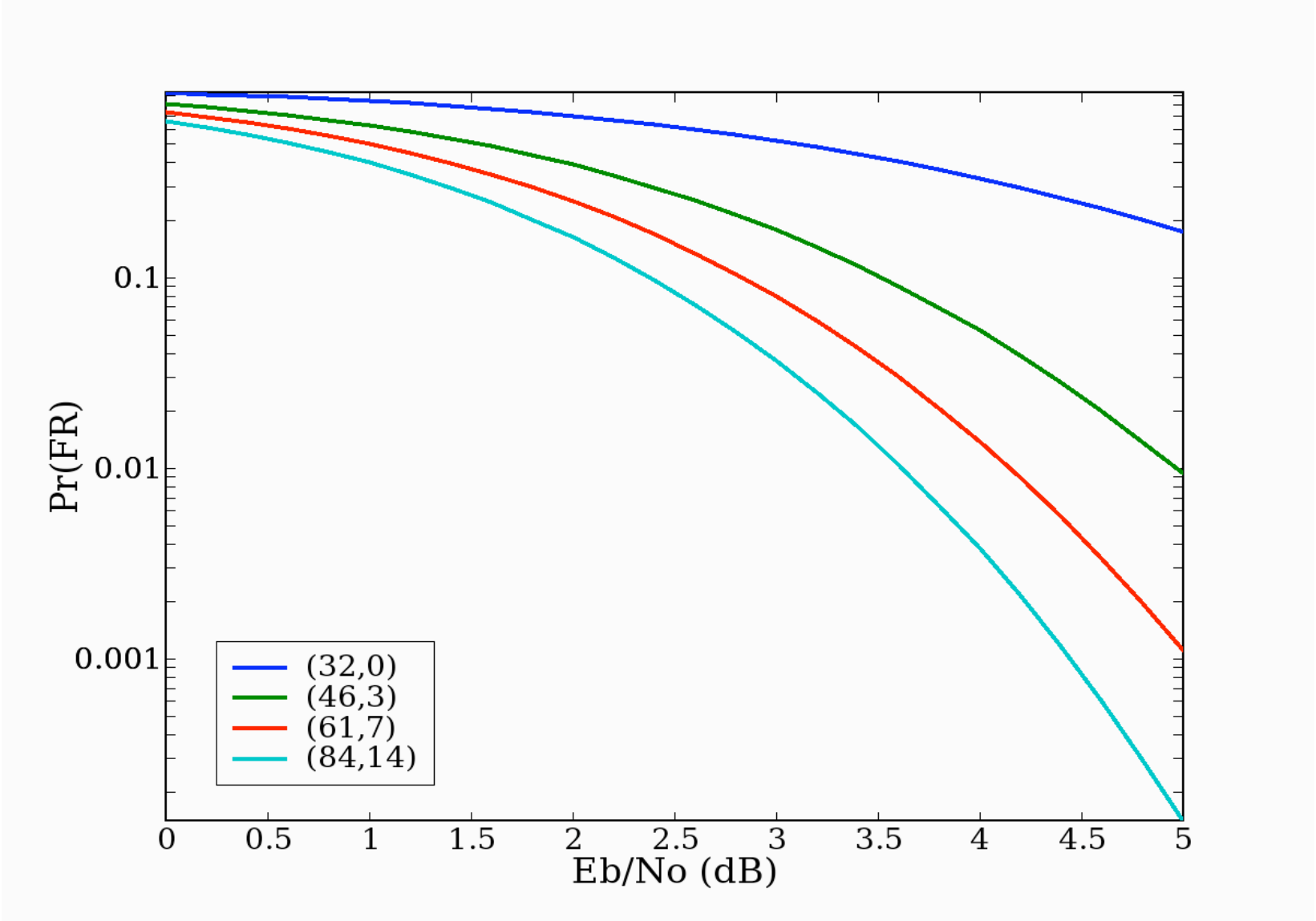
Soft-Decision Message Authentication



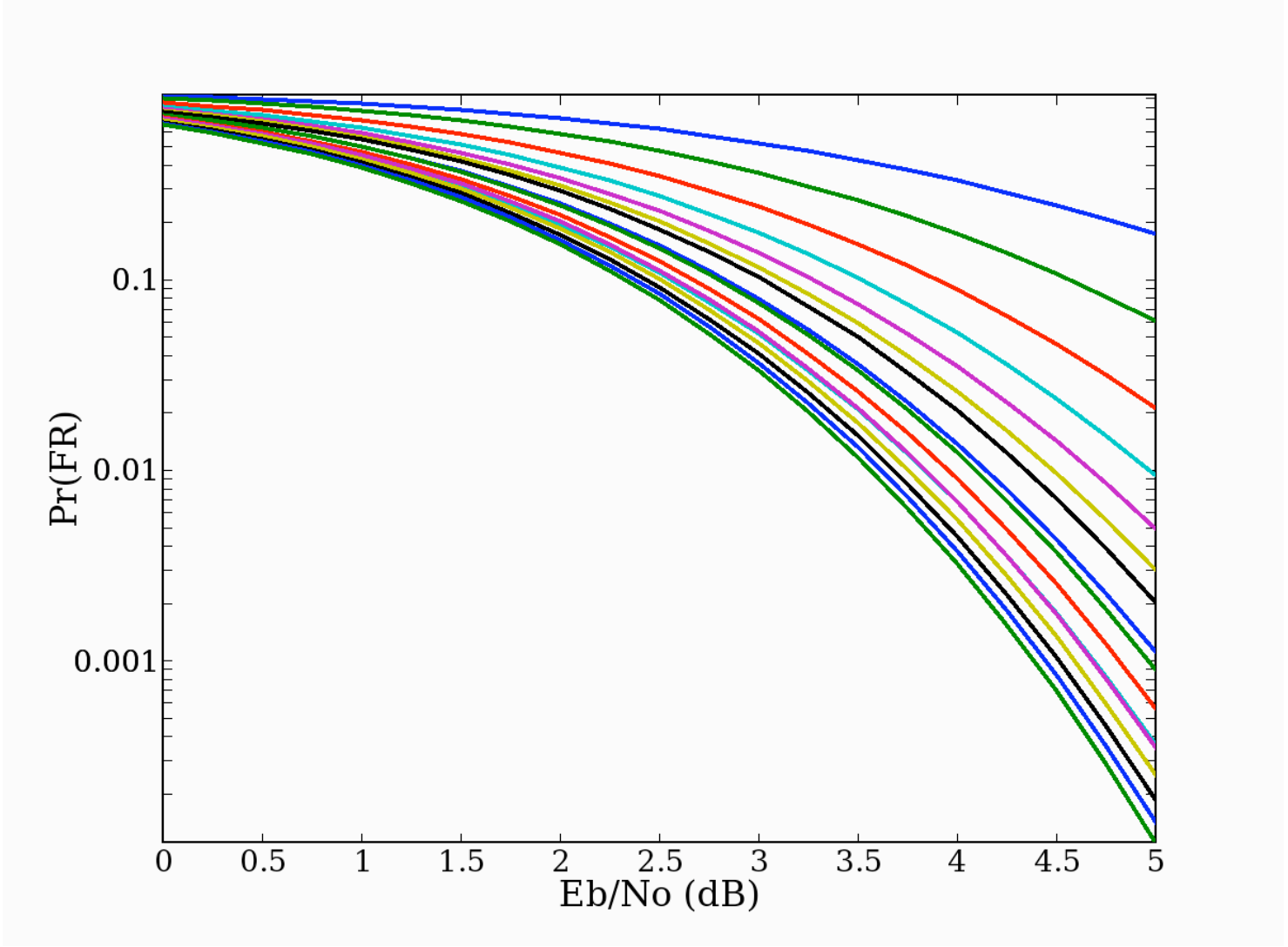
Hard Bit Tag

- Normally one specifies *P(False Accept),* e.g., *2**-s* for *s* bits of "power"
- Then one minimizes *P(False Reject).*
- Instead of doing ECC, do the following:
  - Transmit *n* tag bits
  - If *k* or fewer errors, accept; else, reject.
- Example: 48 bits of power can be achieved with *(n,k)=(48,0), (54,1), (59,2), (64,3), (68,4),* etc.

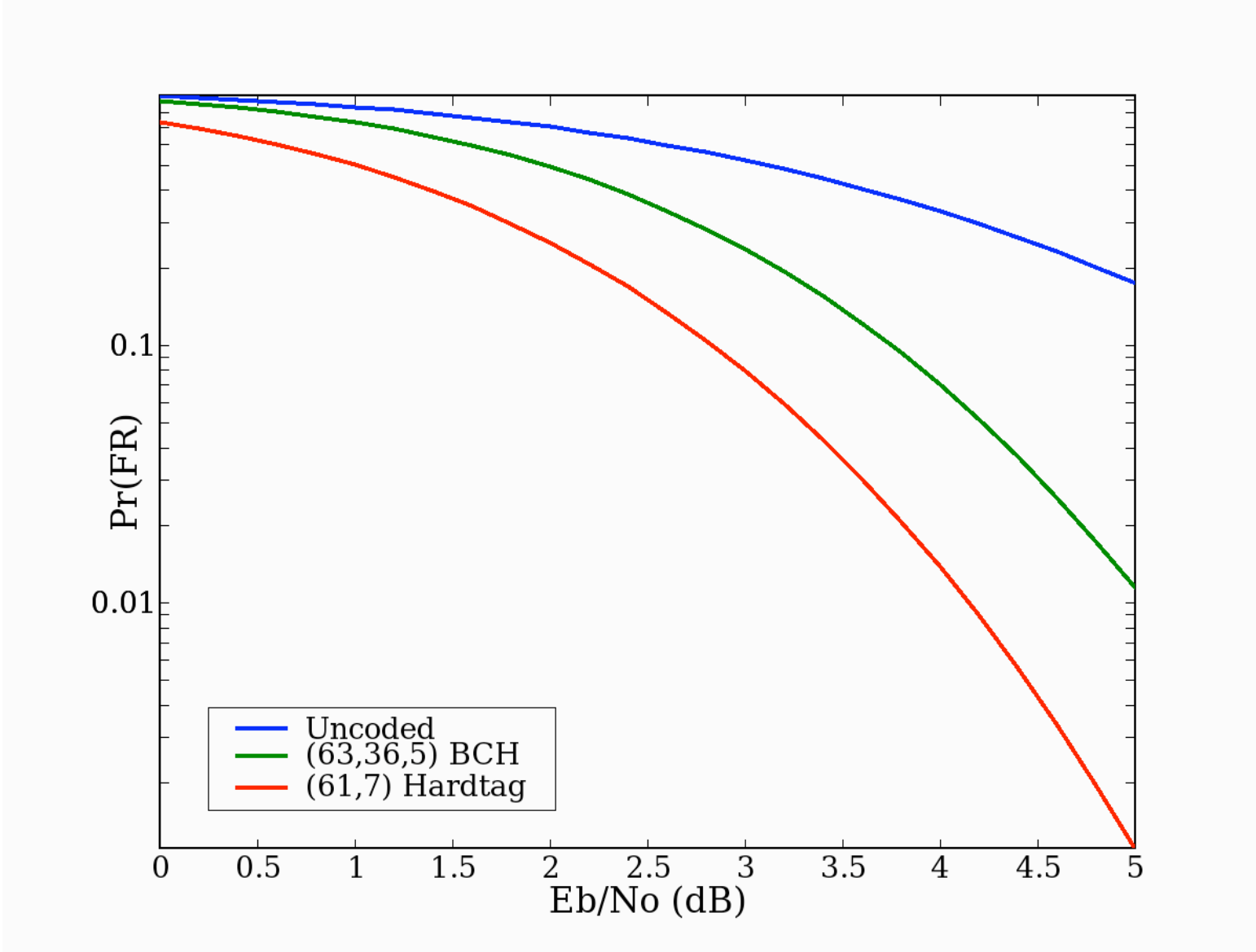
Hard Bit Tag Performance



Hard Tag Detailed Performance



Hard Tag vs. ECC



Hard Bit Tag (ctd.)

- Hard Bit Tag is *extremely* simple to implement: Generate *n* bits and count the number of bits in error.
- The Hard Bit Tag will outperform *any* (hard decision) ECC based scheme of same length.

Soft Tag

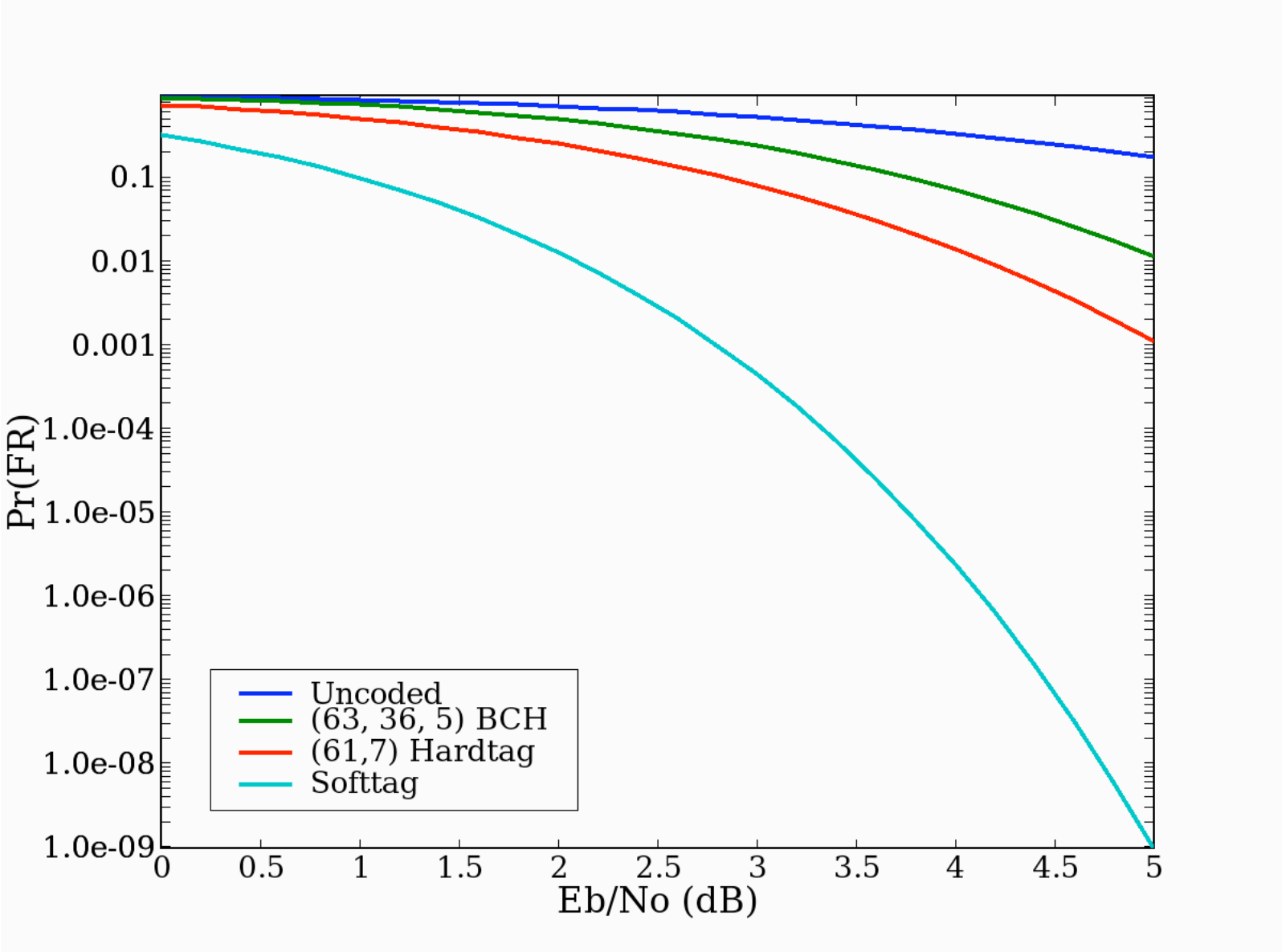
- Instead of hard decoding each bit, do soft decoding.
- If message is correct, $X \sim N(-1, \sigma^2)$
- If *message is incorrect,* $X \sim 0.5N(-1, \sigma^2)+0.5N(1, \sigma^2)$

- *Log likelihood ratio is* $l(X) = \log(e^{aX}+1)/a$
- *Where* $a=2/\sigma^2$

Soft Tag Performance

- Use numerical techniques to compute density of $I(X_i)$
- Convolve to get density of sum of $I(X_i)$
- *Difficult computation since desired error probabilities are very small, e.g., 2**-32=2e-10, 2**-48=3e-15*

Soft Tag Performance



Message Authentication via Non-Spread Soft-Decision Decoding

- Original concept reduced tag size and increased tag reliability by performing hard-decision decoding of new spread spectrum-based waveforms
- Problem: Some communications systems may not be amenable to spreading or the burden of cross-layer packet decoding
- Alternate goal: Apply message authentication in such a way that is more generalizable
- ***Concept:*** *Perform soft-decision decoding of a traditional uncoded message authentication tag*

Soft-Decision Decoding Approach

- Traditional Approach:
  - Demodulate, soft/hard decode, hard correct message and tag bits
  - **Verify using hard-corrected message and tag bits**
    - ***Do computed and received tags match bit-for-bit?***
- Soft-Decision Decoding Approach:
  - Demodulate, soft decode, hard correct message bits
  - **Verify using hard-corrected message and soft-decoded tag bits**
    - ***Do computed and received tag bit values match "close enough"?***

Soft-Decision Verification Security

- Two ways soft-decision verification can incorrectly mark a incorrect message as authentic (false accept failure):
  - Failure 1. Incorrectly received message results in the receiver computing a hard-decision MAC tag that is a hard bit-for-bit match ("collision") with the received authentication tag (same as traditional message authentication risk)
  - Failure 2. Incorrectly received message results in the receiver computing a hard-decision MAC tag that is not a hard bit-for-bit match, but using soft-decision verification is "close enough"
- Our Security Approach
  - Make sure probability of *either* of the two events is less than the desired probability of forgery

Addressing “Hard” Collision Security

- To guarantee resilience against traditional collisions (Failure 1), we propose to generate and verify an authentication tag that contains at least n_{min} bits, where:

  Desired *Pr(False Accept)* = $2^{-n_{min}}$

  Example:

  If the Desired *Pr(False Accept)* = 2^{-48}, then

  n_{min} = *48* bits

- Total tag size is $n = n_{min} + n'$

Addressing "Soft" Collision Security

- To guarantee resilience against soft-decision collisions (Failure 2), we propose to generate and verify an authentication tag that contains:

$$n = n_{min} + n' \text{ bits}$$

- Next we determine n'
- Our soft-decision must evaluate two hypotheses:

H_0 (authentic): $X_i \sim N(1, \sigma^2)$

H_1 (not authentic): $X_i \sim 0.5*N(1, \sigma^2) + 0.5*N(-1, \sigma^2)$

  - where X is an unbounded continuous value where 1 indicates that the received and computed bits match, and -1 indicates that they do not match
  - σ^2 is dependent on the signal-to-noise ratio

Sample Means for the Two Hypotheses

- As a practical matter, X_i will be bounded by 1 to -1, so revise H_0 s.t.:

$$\_0 = (1-.68*\sigma^2) \quad \textit{(assuming BPSK)}$$

- Mean of H_0 for all n samples is:

$$n\_0 = n*(1-.68*\sigma^2)$$

and for H_1 ,

$$n\_1 = 0$$

- However, the worse case forgery condition is a hard-decision bit-by-bit collision, so to be conservative, set

$$n\_1 = n_{min}*(1-.68*\sigma^2)$$

Setting the Verification Threshold

- The simplistic approach is to set the threshold at the *midpoint* between the means of the two hypotheses, this way the false accept (verify bad message) and false reject (reject good message) rates of the verification function are the same
- Thus, the threshold is:

$$t = \_ * (\_n_0 + \_n_1)$$

$$t = n_{min} + n' * (1-.68*\sigma^2) / 2$$

Authentication Tag Size Determination

- Since we are assuming AWGN and normal distribution, the z value that corresponds to a probability of forgery of 2^{-48} is *7.79*
- Thus,

$$n' * (1-.68*\sigma^2) / 2 = 7.79 *\sigma^2$$

- Solving for n':

$$n' = \frac{2 * 7.79 *\sigma^2}{(1-.68*\sigma^2)}$$

Example of Traditional Method

- Assume we wish to authenticate a 16-bit message with probability of forgery per attempt of 2^{-48}
- Traditional method:
  - Generate and append 48-bit MAC tag
  - Generate and append 63 parity bits using a Binary BCH block code with n = 127, k = 64, t = 10 errors
  - **Communicate <u>127 bits</u>**

Example of Soft-Decision Authentication Method

- First, determine *n'* by selecting the worst signal-to-noise ratio that would we expect to verify messages
  - Since the (n=127,k=64,t=10) BCH code can correct up to 10 errors, assume our worst case probability of bit error:

    $p_E = 10.5/127 = .083$
  - For BPSK, $E_b/N_0 = -.15\ dB$
  - Thus, *n' = ceiling (12.45) =* ***13 bits***

Soft-Decision Message Composition

- So for the same 16-bit message and probability of forgery = 2^{-48} :
  - Reduced packet size approach:
    - Generate and append a 48+13 = 61 bit MAC tag
    - Generate and append 15 bits using a (n=31, k=16, t=3) Binary BCH code
    - **Communicate <u>92 bits</u>**
    - ***Less bits than traditional method with at least same security and modestly better reliability***
  - Increased packet reliability approach:
    - Generate and append a 48+16 = 64 bit MAC tag
    - Generate and append 47 bits using a (n=63, k=16, t=11) Binary BCH code
    - **Communicate <u>127 bits</u>**
    - ***Same bits as traditional method with at least same security and much better packet reliability***

Soft-Decision Authentication Plans

- Remainder of FY04
  - Analytically examine the soft-decision authentication approach for various
    - Bit/packet error rates
    - Packet/message sizes
    - Security levels
  - Simulate the soft-decision authentication approach for various
    - Bit/packet error rates
    - Packet/message sizes
    - Security levels

Output

- Submitted paper to Milcom (acceptance pending), paper to NATO workshop (accepted).
- In process of writing 1-3 journal articles.
- Developing software to analyze and simulate these tags.